2015 INTERNATIONAL WORKSHOP ON ENVIRONMENT AND ALTERNATIVE ENERGY
"Increasing Space Mission Resiliency through Sustainability"
(NASA – ESA – C3P)

Infrastructure Resiliency through Sustainability: Complex Adaptive System Approach

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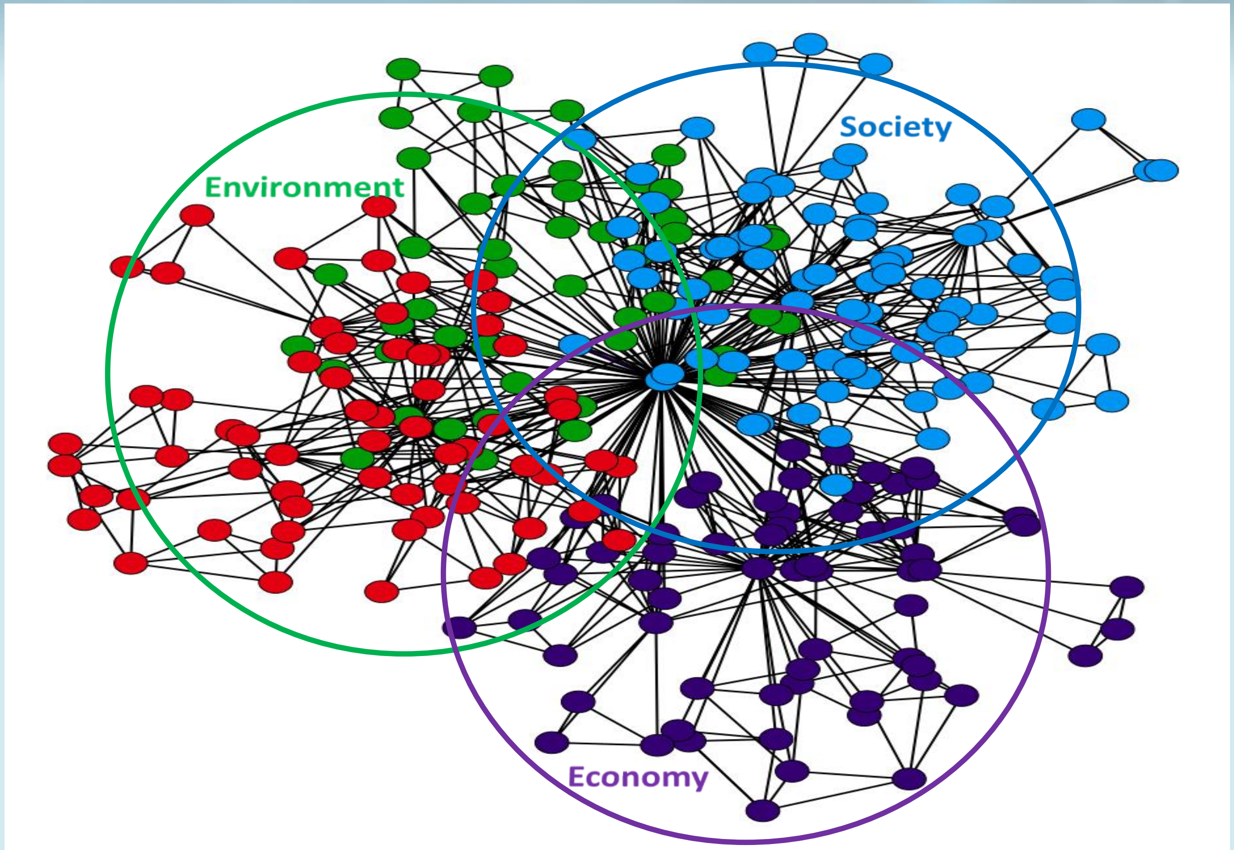
Sustainable systems



Pursuit of sustainable development requires a system approach to the design of industrial product and service systems.
Sustainability is not a goal or an end state that we should collectively aspire rather it is a characteristic of a dynamic evolving system.
The concept of “resilience” borrowed from the field of ecology, enables sustainability to be viewed as an inherent system property rather than an abstract goal.

Keywords

Complex Adaptive System can be defined as **structured set** of many diverse and **autonomous subsystems** called agents (being CAS themselves) which are **interrelated**, **interdependent**, linked through many **interconnections**, and **behave as a unified whole** in **learning from experience** and in **adjusting (not just reacting) to changes** in the environment. Each agent maintains itself in an environment which it creates through its interactions with other agents. Every CAS is **more than the sum of its constituting agents** and its behavior and properties **cannot be predicted** from the **non-linear dynamics**, the behaviors and properties of the agents. CAS are characterized by diffused (distributed) and **not centralized control** and, unlike rigid (mechanistic) systems, they change in **response to the feedback received from their environment to survive and thrive in new situations**. The **emergent patterns** are more than the sum of the parts, thus the traditional reductionist methodology fails to describe how the macroscopic patterns emerge. Within such a context, change needs to be seen in terms of **co-evolution** with all other related systems, rather than as **adaptation to a separate and distinct environment**.

Infrastructure Resiliency through Sustainability

Rainforest trees in the "wet desert"

- ✓ **Diversity**: existence of multiple forms and behaviors;
- ✓ **Efficiency**: performance with modest resource consumption;
- ✓ **Adaptability**: flexibility to change in response to new pressures;
- ✓ **Cohesion**: existence of unifying forces or linkages.

Grimshaw's Eden Project, Cornwall, UK

Namib Desert beetle

Sea water Greenhouse. A biomimicry application in Tenerife - M. Pawlyn

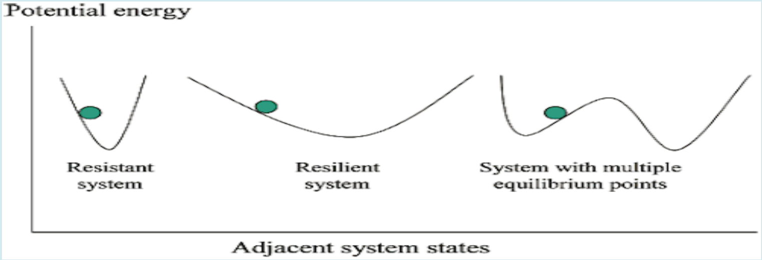
Distributed eco-systems typify a novel approach to systems engineering, sometimes called "biomimicry", that more closely resembles the patterns seen in nature.

The emergent properties of open systems give them the capacity to tolerate perturbations and to evolve into new, unimagined forms.

Resiliency and Sustainability

System theory is the study of how complex entities interact openly with their environments and evolving continually by acquiring new, “emergent” properties. Rather than reducing an entity to the properties of its parts, system theory focuses on the relationships between the parts that connects them into a whole. It turns out that many system properties are independent of the concrete substance of their elements.
Complex systems are general dynamic, non linear, and capable of self-organization to sustain their existence.

The real essence of sustainability is resilience, the ability to resist disorder.



Based on an understanding of complex systems' patterns, humans may be able to intervene in appropriate ways that take advantage of the system dynamics rather than merely resisting change.

Infrastructure Resiliency through Sustainability

It is possible to explore the properties of both natural and engineered systems that make them more or less resilient. Several key characteristics of living systems that can also be extended to industrial systems.

One of the challenges for sustainable system design is to identify major system characteristics that contribute to resilience and to interpret them in the context of the nested systems.

Some of these characteristics are:

- **Diversity**: existence of multiple forms and behaviors;
- **Efficiency**: performance with modest resource consumption;
- **Adaptability**: flexibility to change in response to new pressures;
- **Cohesion**: existence of unifying forces or linkages.

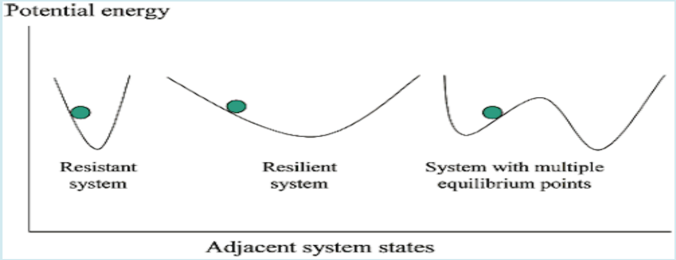
Infrastructure Resiliency

In the past, the civil engineering profession has emphasized the resilient design of the individual infrastructure components that make up these systems but less attention has been paid to how infrastructure components interrelate and interact internally and externally to make up a dynamic adaptive system.

As a result, environmental, social and economic disruptions have revealed that society is vulnerable to catastrophic cascading failures that occur due to a lack of resiliency in the points of interconnection between individual infrastructure and environmental, social, economic systems.

Traditional systems engineering practices try to anticipate and **resist** disruptions but may be vulnerable to unforeseen factors.

The real essence of sustainability is resilience, the ability to resist disorder



A paradigm shift is to engineer and design systems with "**inherent resilience**" by taking advantage of fundamental properties such as diversity, efficiency, adaptability and cohesion. This approach leads to the consideration of resilience in both engineered systems and the larger systems in which they are embedded.

The design of engineered systems has been approached traditionally as a process of hierarchical decomposition : the overall system function and architecture are developed first and then the systems and subsystems are designed accordingly.

Complex, hierarchically organized systems (e.g., aircraft, nuclear plants) tend to have rigid operating parameters, are resistant to stress only within narrow boundaries, and may be vulnerable to small, unforeseen perturbations.

Alternatively, distributed systems composed of independent yet interactive elements may deliver equivalent or better functionality with greater resilience.

Examples:

- A collection of distributed electric generators (e.g., fuel cells) connected to a power grid may be more reliable than a central power station.

- A geographically dispersed workforce linked by telecommunications may be less vulnerable to catastrophic events that could destroy a single facility.

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The increasing connectedness of among industrial, ecological, and social systems creates new opportunities but also exposes society to greater risks.

Sustainable system design should proceed with a constant awareness of related systems, boundary conditions, external effects, and potential feedback loops.

It is necessary to address new technical challenges in creative ways:

- Requirements to include system behaviors rather than just outcomes;
- Predictive modeling to explore scenario building;
- Design strategies to rely upon intervention rather than control;
- Robustness to be achieved through resilience rather than resistance;
- Risk management to draw upon new concepts such as adaptivity and diversity;
- System state indicators to be based on fundamental energy attributes.

The resilience perspective has important implications for companies that wish to become more sustainable. It is not sufficient for a company to redesign only those systems that it fully controls.

Companies that wish to ensure their long-term resilience must reach beyond their own boundaries, develop an understanding of the systems in which they participate, and strive for continuous innovation and renewal.

Strategic adaptation becomes more important than strategic planning, and decision makers need to manage uncertainty rather than trying to eliminate it.

"Any company that can make sense of its environment, generate strategic options, and re-align its resources faster than its rivals will enjoy a decisive advantage. This is the essence of resilience "

Hamel, G.; Valikangas, L. The Quest for Resilience. Harvard Business Rev. 2003, September.

Thank you for your attention.

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